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Total charge transfer cross-sections for protons colliding with hydrogen atom

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Abstract. Total charge transfer cross-sections for protons impinging on hydrogen has been calculated in Coulomb-projected Börn approximation. It is seen that the present calculation compares well with the available experimental data.

Keywords. Charge transfer; cross-sections; Coulomb-projected Born approximation.

1. Introduction

The charge transfer process in ion-atom collisions is responsible for various physical phenomena occurring in upper atmosphere and thermonuclear fusion plasma (Barnett 1976; Lorenz *et al* 1976). The simplest charge transfer process

$$H^+ + H(1s) \rightarrow H(n\ell) + H^+$$

has been investigated in recent years by Belkic and Gayet (1977) in the continuum distorted wave approximation (CDW) and by Dewangan (1977) in the eikonal approximation. The problem has been explored earlier by various authors (Bates and McCarroll 1962; Bransden and Chesire 1963; Chesire 1963, 1964; Coleman and McDowell 1965 and Coleman 1969). Very recently Basu *et al* (1978) have dealt in detail the different theoretical approaches describing the charge transfer process for protons and α particles incident on hydrogen, helium and molecular hydrogen. In our recent communication (Lal *et al* 1978) we have applied the Coulomb-projected Born (CPB) approximation to study the angular distribution and total charge transfer cross-section to the ground state of H in the case of protons incident on hydrogenic systems. No comprehensive comparison of the results of theoretical calculations with experimental data was attempted. The main object of the present calculation is to report our results for the total charge transfer cross section including contribution of the $n = 2$ state. The contribution of higher states is estimated by a simple empirical relation suggested by Salin (1970). The details of the formulation have earlier been given by Lal *et al* (1978).

2. Results and discussion

We have calculated the total charge transfer cross-sections for protons colliding on hydrogenic target using the CPB method in the energy range 10 keV to 5 MeV. Figure 1a displays the present results in the energy range 10 to 100 keV whereas figure 1b shows the situation in the energy range 100 keV to 5 MeV. We have also shown in these figures the experimental data of Fite *et al* (1960), McClure (1966) and Wittkower *et al* (1966) in the low energy region and Barnett and Reynolds (1958); Schryber (1968); Toburen *et al* (1968) and Welsch *et al* (1967) in the high energy. The

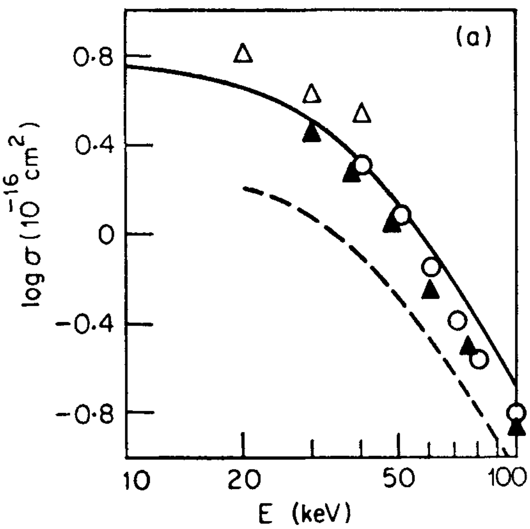

Figure 1a. Total charge transfer cross sections for protons on hydrogen. Present calculation (CPB) ———; eikonal approximation (Dewangan 1977) — — — — —. Experimental data: Fite *et al* (1960) Δ; McClure (1966) ▲; Wittkower *et al* (1966) O;

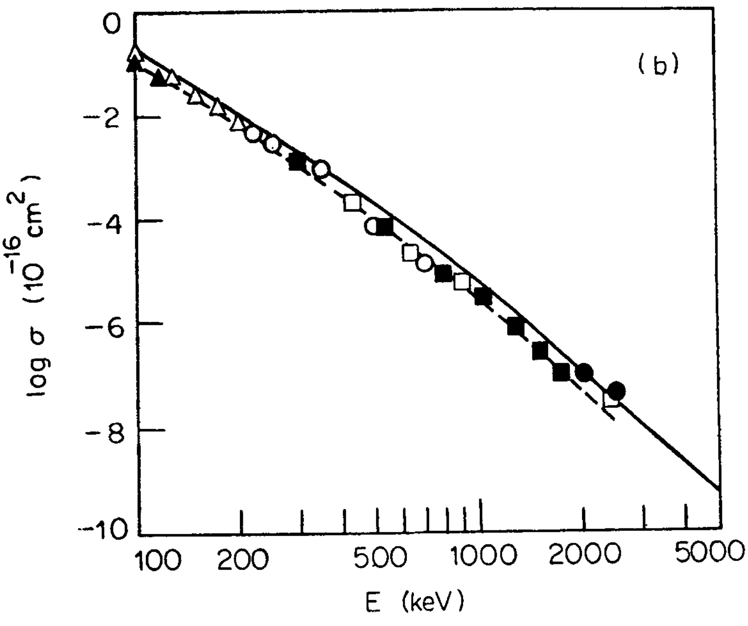

Figure 1b. Total charge transfer cross section for protons on hydrogen. Present calculation (CPB) ———; eikonal approximation (Dewangan 1977) — — — — —. Experimental data: Barnett and Reynold (1958) O; Welsch *et al* (1967) □; Schryber (1968) ■; Toburen *et al* (1968) ●; Wittkower *et al* (1966) Δ; McClure (1966) ▲.

Table 1. The CPB cross sections for $H^+ + H(1s) \rightarrow H(f) + H^+$ (in units of a_0^2)

E (keV)	$1s$	$2s$	$2p_x$	$2p_z$
5	1.53^{1}*	9.12^{-3}	$2{\cdot}78^{-3}$	6.98^{-3}
10	2.10^{1}	9.62^{-2}	2.05^{-2}	6.44^{-2}
20	1.50^{1}	$4{\cdot}31^{-1}$	$6{\cdot}74^{-2}$	$2{\cdot}55^{-1}$
30	9.39	$6{\cdot}18^{-1}$	$9{\cdot}10^{-2}$	$3{\cdot}22^{-1}$
40	5·83	$5{\cdot}40^{-1}$	$7{\cdot}42^{-2}$	$2{\cdot}66^{-1}$
50	3·70	$4{\cdot}20^{-1}$	$5{\cdot}29^{-2}$	$1{\cdot}95^{-1}$
100	$5{\cdot}75^{-1}$	$8{\cdot}73^{-2}$	$7{\cdot}15^{-3}$	$3{\cdot}04^{-2}$
500	$6{\cdot}34^{-4}$	$9{\cdot}09^{-5}$	$1{\cdot}82^{-6}$	$9{\cdot}76^{-6}$
1000	$1{\cdot}65^{-5}$	$2{\cdot}22^{-6}$	$2{\cdot}30^{-8}$	$1{\cdot}29^{-7}$
5000	$1{\cdot}71^{-9}$	$2{\cdot}16^{-10}$	$4{\cdot}70^{-13}$	$2{\cdot}72^{-12}$

*Superscript denotes the power of 10 by which the number is to be multiplied.

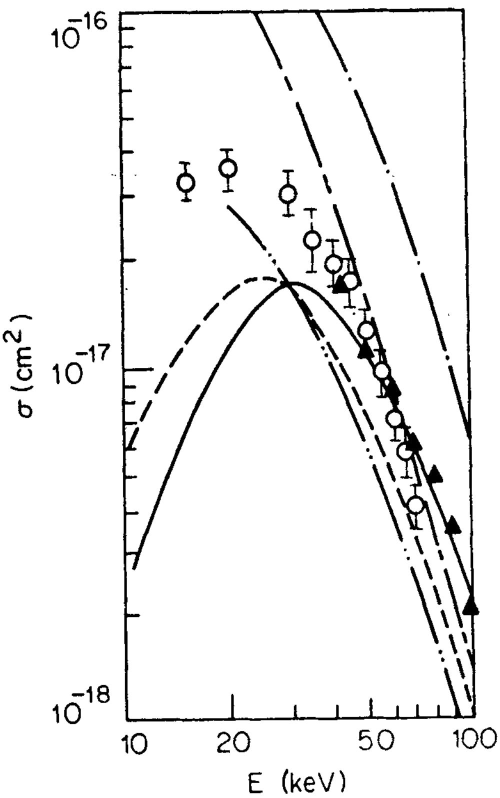

Figure 2. Charge transfer cross sections ($2s$ capture) for protons on hydrogen. Present calculations; (CPB) ————; (OBK) —·—·—; CDW (Salin 1971) — — — —; impulse approximation (Coleman and McDowell 1965) — .. — .. —; eikonal approximation (Dewangan 1977) — — — —. Experimental data: Bayfield (1969) ♀; Ryding *et al* (1966) ▲.

recent theoretical results of Dewangan (1977) in the eikonal approximation are also displayed. Figure 1a shows that the agreement of the present results with the experimental data is better compared to the eikonal approximation which underestimates the total cross-section on an average by a factor of 3. We believe that it may be due to the usual faster decay of eikonal differential cross-section leading to smaller total result. Figure 1b also shows a good agreement of the present results with the experimental data. It is worth mentioning here that the experimental charge transfer results which are being compared with the theoretical results, are obtained by dividing the molecular hydrogen capture cross-section data by a factor of 2. A quantitative estimate of the contribution to the total charge transfer cross-section by various final states is given in table 1. It is found that the charge transfer to 2*s* state of atomic hydrogen contributes on an average about 20% to the total contribution in the intermediate energy region, whereas the contribution arising from 2*p* states falls off very rapidly, never exceeding beyond 6%.

Figure 2 shows the total charge transfer cross-sections into 2*s* state in the energy range 10 to 100 keV. These results have been compared with the measurements of Bayfield (1969) and Ryding *et al* (1966) and with the theoretical results of Salin (1971) in the CDW method, Dewangan (1977) in the eikonal approximation and Coleman and McDowell (1965) in the impulse approximation. It is observed that the experimental results of Ryding *et al* (1966) are well predicted by the present CPB results in the energy range 40 to 100 keV. The measurements of Ryding *et al* (1966) have been normalized to those of Bayfield at 44 keV (as given in the paper of Bayfield). The

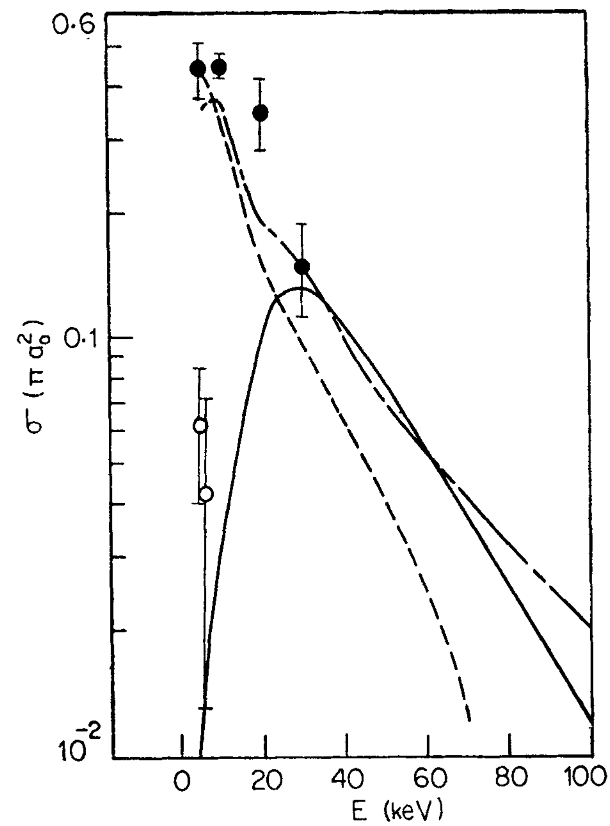

Figure 3. Charge transfer cross section (2*p* capture) for protons on hydrogen. Present calculation ———; pseudo state calculation (Chesire *et al* 1970) — — — —; close-coupling results (Rapp and Dinwiddie 1972) — — — — —. Experimental data: Stebbings *et al* (1965) ⧳; Gaily and Geballe (1970) ⧲.

measurements of Bayfield in this energy region fall somewhat more rapidly and differ with our results by as much as a factor of 1·5 at 70 keV. However, they compare fairly well with Salin's (1971) results down to 40 keV. Figure 3 shows our results for capture into $2p$ states. It is seen that the theoretical results show a large deviation from the experimental data of Stebbings *et al* (1965) and Gaily and Geballe (1970). The experimental measurements are available only in a very small energy region up to 30 keV.

The present investigation indicates that the present total charge transfer results obtained in the CPB approximation yield a reliable estimate of the cross-section even for lower energies than is usually expected.

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